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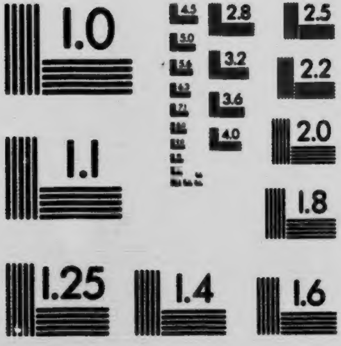

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ON THE IONISATION BY COLLISION IN THE GASES HELIUM AND ARGON

BY

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ON THE IONISATION BY COLLISION IN THE GASES HELIUM AND ARGON.*

INTRODUCTION.

The theory of electrical conduction through gases has been discussed by Professor Thomson in his "Conduction of Electricity through Gases,"[1] and by Professor Townsend in several papers in the Philosophical Magazine,[2] and the theory has been carefully tested by the latter for the gases air, hydrogen and carbon-dioxide. According to this theory the electric current through a gas filling the space between two metal electrodes, and ionised by a constant external source of radiation, varies in three stages with a series of increasing electric fields. At first the current increases at a rate proportional to the applied field, then at a less rate until it reaches practically a steady value, showing very little increase for comparatively large changes of potential, and finally, it again increases more and more rapidly with the field until a luminous discharge passes. The current-potential curve is thus of the type illustrated in the following diagram, in which *OA*, *BC* and *CD* represent the three stages, the part *CD* being asymptotic to the sparking potential value of the field.

The characteristics of this curve may be accounted for in a general way as follows: Ions are produced in the gas at a certain rate by the radiation from the external source, and are removed at corresponding rates by (1) the electric field and (2) recombination. A certain range of fields removes them as quickly as they are formed, and the corresponding current constitutes the saturation current. In order to explain the subsequent increase in current it is sufficient to suppose that a number of neutral molecules are ionised by collision with either negative or positive ions to which the field has given sufficient energy. In this connection Townsend has introduced two coefficients, α and β, which are defined as the number of molecules ionised respectively by a negative ion and by a positive ion in moving a distance of one centimetre in the direction of the lines of force; for the saturation current α and β are each zero, and, as the electric field is increased, each increases continuously from zero value. α, however, increases more rapidly at first, so that for the first part of the rise in the curve β is still negligible. For the latter part β is still very small, but here it accounts for very great increases in the current.

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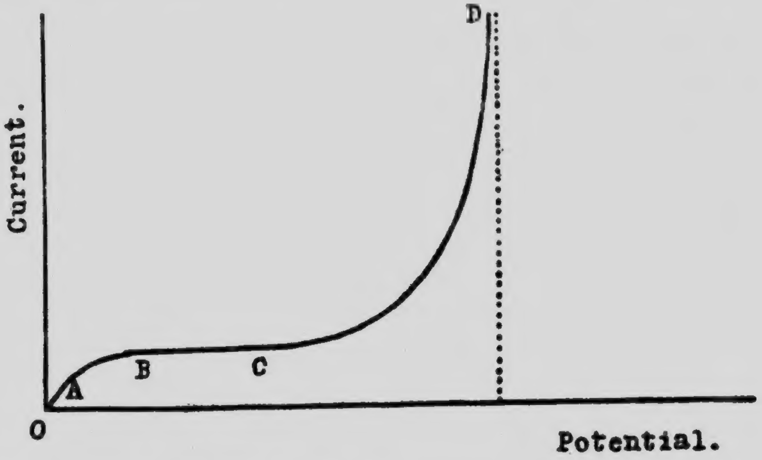
* Recommended for publication in the University of Toronto Studies by Professor J. C. McLennan, Director of the Physical Laboratory, University of Toronto.

[1] Page 471 et seq.

[2] Townsend, Phil. Mag., VI, 1, 198. Townsend and Kirkby, Phil. Mag., VI, 1, 630. Townsend, Phil. Mag., VI, 6, 598.

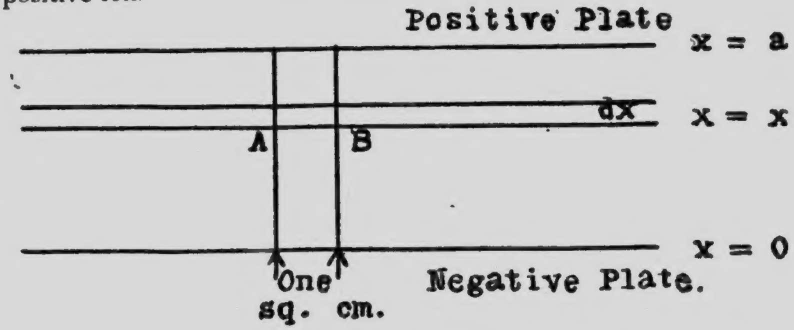


The present paper is an account of experiments undertaken to determine a series of values of α and β for the monatomic gases Helium and Argon. The case of helium seemed of particular interest on account of the well-known ease with which a luminous discharge passes through it at comparatively high pressures.

THEORY OF EXPERIMENT.

In his first experiments Townsend used Röntgen rays as the source of primary ionisation, and in the later ones ultraviolet light falling on a zinc plate. In the following experiments the source was a thin uniform layer of uranium oxide spread over a metal plate which also served as one electrode. The second electrode was a plate parallel to the first. The use of this arrangement afforded two advantages over other sources of ionisation, viz., the ionising radiation was uniformly distributed throughout the space between the plates, and, secondly, the radiation could be depended upon to remain constant during all sets of readings. In order to obtain numerical relations for the values of α and β, we may adapt to the case of ionisation by uranium the line of reasoning worked out by Townsend for ionisation by Röntgen and ultraviolet rays.

1. In the first place we shall obtain an expression for the current density between the plates. Consider the ionisation in a cylinder of one square centimetre section extending from the one plate to the other. Let n be the number of molecules ionised per second within this cylinder, n will then be the number of positive and of negative ions formed in the cylinder, and in the steady state n positive ions will go per second to the negative plate, and n negative ions per second to the positive plate, so that the current density between the plates will be ne where e is the charge on each positive ion.



Let the negative plate be taken as the plane $x=0$ and the positive plate $x=a$, and let AB be a plane at a distance x from the former. Let q be the number of negative ions freed per second between the negative plate and AB. Then $(n-q)$ will be the number freed between AB and the positive plate; and these numbers, q and $(n-q)$, will be also the numbers of positive ions formed per second in these two regions.

Let α, β be the coefficients of ionisation by collision, as defined on page 4, for a field of strength X, and let k be the number of molecules ionised per c.cm. by the uranium oxide.

In the steady state q negative ions will pass per second through the thin layer of gas of thickness dx at AB, so that in this layer $q\alpha dx$ molecules will be ionised per second by the negative ions. Similarly $(n-q)\beta dx$ molecules will be ionised per second by the positive ions. Also the number kdx will be ionised by the uranium.

Hence
$$dq = (q\alpha + \overline{n-q} \cdot \beta + k)dx$$

or
$$\frac{dq}{q + \dfrac{n\beta + k}{\alpha - \beta}} = (\alpha - \beta)dx$$

and, integrating between the limits 0 and n for q and 0 and a for x,
$$1 + \frac{n(\alpha - \beta)}{n\beta + k} = e^{(\alpha - \beta)a}$$

from which
$$n = \frac{k\{e^{(\alpha - \beta)a} - 1\}}{\alpha - \beta e^{(\alpha - \beta)a}}$$

The value of the saturation current is given by putting α and β each equal to zero,
$$n_0 = ka$$

Substituting for k in terms of n_0 gives
$$\frac{n}{n_0} = \frac{e^{(\alpha - \beta)a} - 1}{a\{\alpha - \beta e^{(\alpha - \beta)a}\}}$$

2. Besides this relation between α, β and n, we may from other considerations deduce some further properties of α and β.[1] We may, for example, arrive at an estimate of the amount of energy necessary to separate a corpuscle from a molecule and thus produce ionisation. We may suppose that the necessary energy is derived from the colliding ion. This energy is imparted to the ion by the electric field as it travels along its free path. The amount of energy so acquired will depend therefore on the strength

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[1] Cf. Townsend, loc. cit.

of field, X, and on the length of the free path. It will thus vary in successive collisions. Let A be the length of the projection of the free path of an ion on the axis of x (diagram of page 5). The energy acquired by the ion will be measured by XA, the potential difference of the ends of its path. The collision at the end of its journey will result in ionisation if this is greater than a certain critical value E. Of all the collisions (y, say, in number) which an ion makes in travelling one centimetre in the direction of the field, those will result in ionisation for which A is greater than $\frac{E}{X}$.

Now, of the y values of A which go to make up one centimetre, the number of those which are greater than A is ye^{-Ay}, and this is therefore the number of collisions resulting in ionisation.

Hence if A_1, E_1 refer to the negative ion and A_2, E_2 to the positive ion, we have

$$\alpha = ye^{-A_1 y}, \quad \beta = ye^{-A_2 y}.$$

Conversely, having determined α and β, we may find values for A_1 and A_2, and thence arrive at an estimate of E_1 and E_2.

3. Further consideration of their properties relates α, β and X with the pressure p of the gas by equation of the form,

$$\frac{\alpha}{p} = \varphi_1\left(\frac{X}{p}\right), \quad \frac{\beta}{p} = \varphi_2\left(\frac{X}{p}\right).$$

This follows at once from the deductions of the preceding article. The number of collisions made by an ion in travelling one centimetre varies as the pressure of the gas, i.e., $y = cp$.

Also, $A_1X = E_1$, $A_2X = E_2$, and E_1, E_2 are constants.

Hence the values for α and β become

$$\frac{\alpha}{p} = ce^{-\frac{p}{X}cE_1}, \quad \frac{\beta}{p} = ce^{-\frac{p}{X}cE_2}.$$

4. For a selected value of X and a series of values of p the values of α and β should increase with p from zero to a maximum value and then decrease again to the limit zero. This relation is in accord with the equations of the last article. It may also be seen directly from physical considerations, in that the two factors which determine the values of α and β are (1) the total number of collisions made by the ion, and (2) the distance travelled between

successive collisions. α, β must each be less than (1). As p increases from zero the first factor will increase, and with it the opportunity for effective collision; on the other hand the free path will continuously decrease, so that presently a smaller and smaller proportion of the ions will have acquired the requisite store of energy before collision.

On the curve $\frac{\alpha}{p}=\varphi\left(\frac{X}{p}\right)$, showing the relation between $\frac{\alpha}{p}$ and $\frac{X}{p}$, the point of contact of the tangent from the origin gives the value of $\frac{X}{p}$ for which α has its maximum pressure value.

For, considering $\frac{\alpha}{p}=\varphi\left(\frac{X}{p}\right)$ as a relation between α and p, the maximum value of α is given by

$$0=\frac{d\alpha}{dp}=\frac{\alpha}{p}\left(1-\frac{1}{p}\cdot\frac{X\cdot\varphi'}{\varphi}\right)$$

$$\text{or, } p=\frac{X\varphi'}{\varphi},\quad \alpha=X\varphi'.$$

The corresponding point on the curve $\left(\frac{X}{p},\frac{\alpha}{p}\right)$ is $\left(\frac{X}{p}\varphi',\ \varphi\right)$, and the line $\frac{x}{\frac{X}{p}\cdot\varphi'}=\frac{y}{\varphi}$, passing through the origin and this point, coincides with the curve at this point.

PREPARATION OF THE HELIUM.

The helium used in the experiment was manufactured in conjunction with Mr. W. Burton by digesting thorianite with sulphuric acid. The arrangement of apparatus for this process is shown in Figure I. The gas was generated in the round-bottomed flask *a* into which the acid was introduced by a thistle tube *b*. The flask communicated by means of glass tubing (with a rubber connection at *c*) to a Töpler pump *d*, and the gas was collected at the exhaust of the pump by an improvised form of Travers' gas siphon *e*.

As the gas passed from the flask to the pump the carbon-dioxide and most of the water vapour were removed by a potash flask and calcium chloride drying tube *f*. Communication with the pump could be stopped at *c* by means of a metal clamp. A mercury gauge *g* served to indicate the pressure in the flask. A reflux condenser *h* was also used on this part of the apparatus.

The process of making the gas was carried out in the following manner. Some thorianite—about fifty grammes—was finely powdered and put into the flask, which was then placed in its position. The whole apparatus was then thoroughly exhausted and the connection at *c* was closed. The thistle funnel was filled with twenty per cent. sulphuric acid (which had been previously boiled in order to drive off as much of the dissolved air as possible) and the acid admitted, a little at a time, to the thorianite. The flask was now

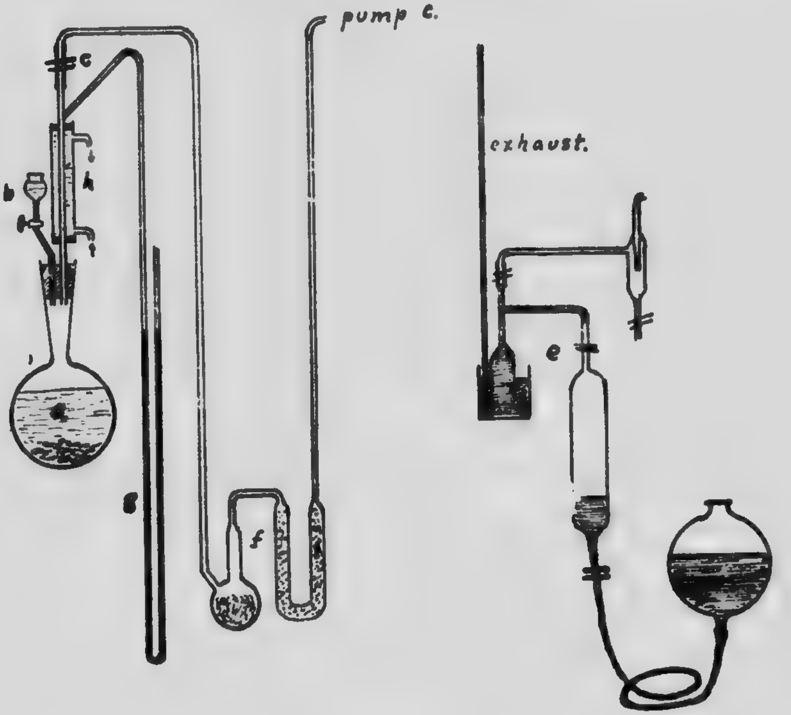

FIGURE I.

heated in a bath of boiling water and the gas was slowly generated. When the pressure in *a* had risen to atmospheric, the clamp at *c* was carefully loosened and the gas admitted to the pump. Communication was again cut off and the flask allowed to fill up again. Meanwhile the gas in the pump was collected. This operation was repeated until the mineral practically ceased to give off gas, and, finally, the whole apparatus was completely exhausted again.

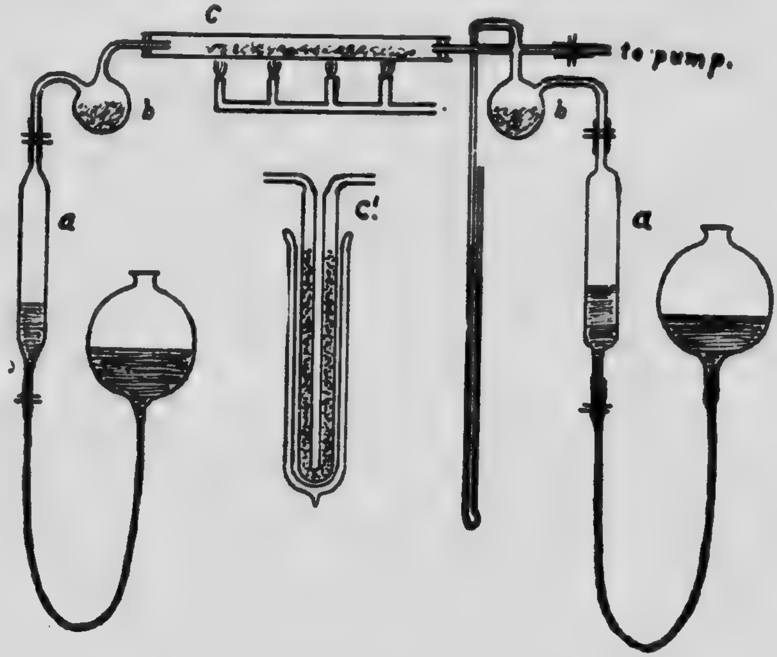

FIGURE II.

In order to purify the gas it was collected in two reservoirs, *a*, *a*, Figure II. It was first passed several times from one reservoir to the other through two phosphorus pentoxide drying tubes, *b*, *b*, and a hard glass tube *c* containing copper oxide which was maintained at a red heat. By this process all the water vapour and hydrogen were removed. A cocoanut charcoal tube *c*, cooled in liquid air, was then substituted for the copper oxide tube and the gas passed several times through it. These operations removed a traces of impurity, not even the hydrogen lines showing in a spectroscopic test. It may be noted, of course, that, when the gas was manufactured by the process described, there was very little impurity in it initially.

By the above process about 450 c.cms. of pure gas was obtained from some 100 gmes. of the mineral.

ARGON.

The argon used was kindly loaned me by Mr. W. Burton, by whom it had been carefully purified. As the apparatus had no perceptible leak, and the gas occupied it for a short time only, it may be taken that the results obtained were characteristic of pure argon.

EXPERIMENTAL ARRANGEMENT.

1. *For Manipulation of the Gases.*—In manipulating the gases it was necessary to provide a means of admitting them at a series of pressures to an ionisation chamber and of collecting them pure at the end of the experiment. As the helium was used in the apparatus before it was made to work satisfactorily, it was also necessary to arrange to repurify the gas. The apparatus used in the case of helium is illustrated in Figure III. In working with argon it was modified by the removal of the tube *d* (see below). The gas was transferred to a long, narrow receiver *a*, the lower end of which could be placed over the exhaust of a Töpler pump *g*. It was admitted to the apparatus through an intermediate chamber *b* which communicated with the reservoir and with the apparatus by rubber connections provided with clamps. This chamber served as a mercury trap, and also allowed the gas to be transferred a small quantity at a time. In passing to the ionisation chamber *c*, the gas traversed a charcoal bulb *d* cooled in the liquid air and a phosphorus pentoxide drying tube *e*. The apparatus could be exhausted by the mercury pump, and the gas on exhaustion was collected in *a*. The gas could be repurified as often as desired by passing it through the charcoal bulb cooled in liquid air. The pure gas was pumped off and collected in the receiver. The impurities were removed from the apparatus by allowing the

charcoal to come to the temperature of the room so that it gave up the absorbed gases; these were then pumped off into the room. In order to facilitate the purifying of the gas and also to make the volume communicating with the ionisation chamber as small as possible, the apparatus could be divided into three parts by means of mercury cut-offs *f*. The ionisation chamber proper was finally made quite air-tight so that the gas in it could only be made impure by the slight amount of other gas given off from the metal parts.

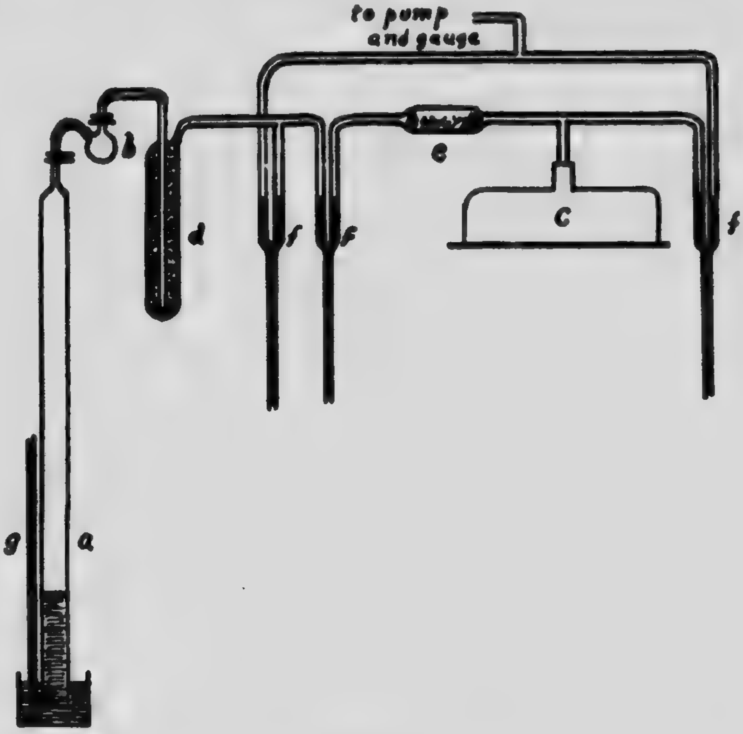

FIGURE III.

The pressures were measured directly by a McLeod gauge when sufficiently small; the larger pressures were all determined in terms of readings of the gauge.

2. *Electrical Part of Apparatus.*—The electrical part of the apparatus is shown in Figure IV*a*. The two electrodes, *a*, *c*, consisted of plane brass plates. The lower electrode *c* was supported by a screw *d*, by means of which its height could be adjusted. The screw was of millimetre pitch, and the rim of *c* was divided into twenty parts so that the position of the electrode could be determined. The axis of the screw was made accurately normal to the upper face of the plate; thus this plane always moved parallel to itself as the system was rotated.

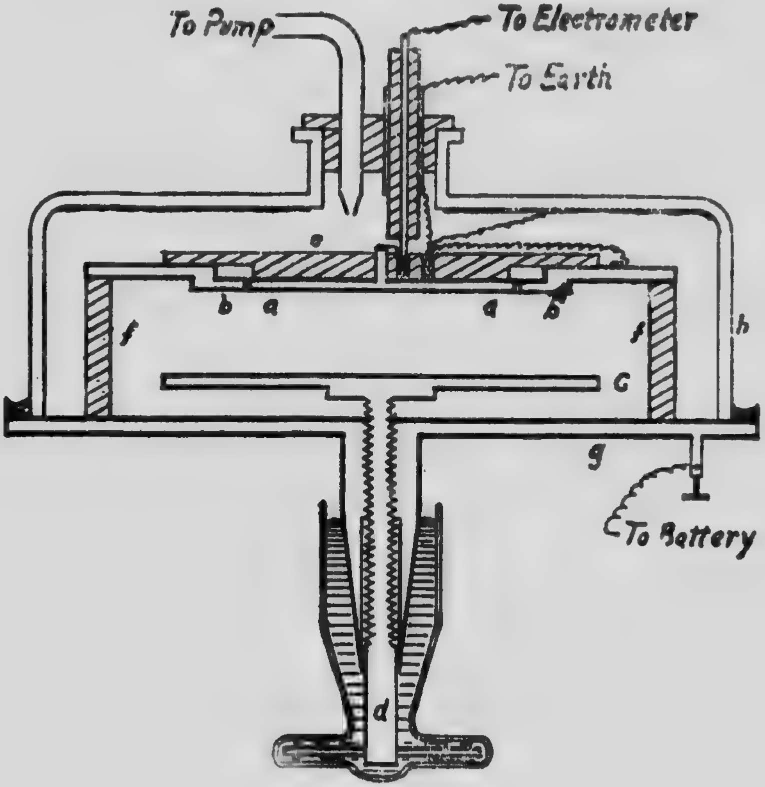

FIGURE IVa.

A great deal of difficulty was encountered in making a satisfactory air-tight collar in which the screw could work. At first a mercury sealed rubber collar was used (as indicated in Figure IV*a*), and a preliminary set of readings was actually made with this arrangement. The method, however, had several disadvantages. In the first place, on account of the tendency of the rubber to stick to the screw it was difficult to rotate the plate without disturbing the rest of the apparatus or even tearing the rubber. On this account it was necessary to arrange to rotate it as seldom as possible. As the object of the experiment required readings of current for a series of distances between the plates and for a series of pressures, the plates had to be placed in each selected position and the gas pressure varied. This arrangement involved a great deal of handling of the gas, and also the observations made in this way were not in very convenient form for making reductions. And finally, the apparatus had to be taken apart several times to renew the rubber collar.

In order to improve these conditions a somewhat modified arrangement was finally adopted (Figure IV*b*). The nut in which the screw worked was extended by means of glass tubing *i* to form a barometer tube dipping into a reservoir *k*. The screw was then worked by a brass rod *m* passing through the mercury of the barometer to the reservoir (the reservoir itself being rotated as well). By this means it was found possible to rotate the screw and so raise or lower *c* quite readily, and readings could be taken with all desired distances without altering the gas pressure.

As indicated above, the primary ionising agent was a layer of uranium oxide spread as uniformly as possible over the lower plate.

The whole was covered by a glass receiver *h* which was cemented with wax to the metal base.

The electrode *c* was charged to any required potential by connection with one terminal of a battery of small storage cells, of which the other terminal was earthed. The current from the charged electrode to the electrode *a* was measured by means of a quadrant electrometer to which *a* was joined by an insulated and shielded metal connection arranged in the usual way. The electrode system could be earthed by a metal contact key. In order to provide for measuring currents over a great range of values, the capacity of the electrode system was made variable by the addition of a condenser of variable capacity. The electrometer used was of the Dolezalek type, but was not very sensitive as it had a rather coarse phosphor bronze suspension. The sensibility was such as to give a deflection of about 86 divisions on a scale at 1.5 metres distance for a potential difference between the quadrants of 1.434 volts.

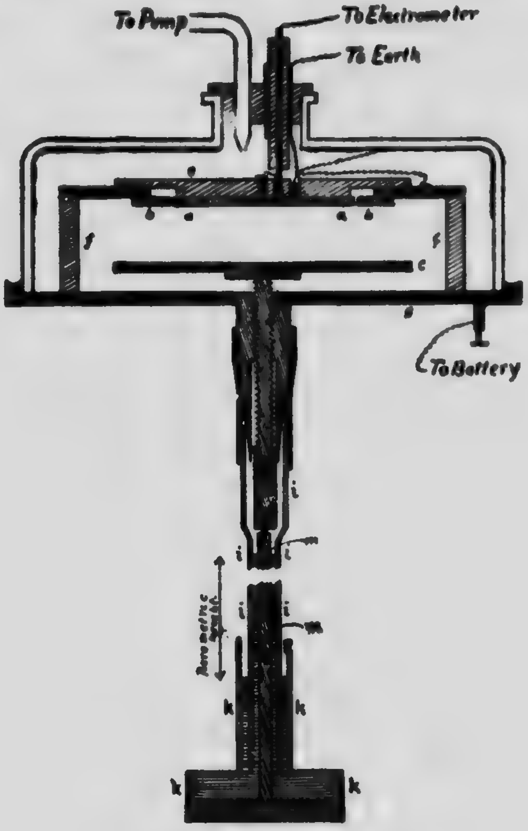

FIGURE IVb.

METHOD OF EXPERIMENT.

The following is an outline of the procedure followed in making the experiments. In the preliminary experiments with the apparatus as in Figure IV*a*, the plate *c* was first adjusted to be a certain distance from *a*, and the whole of the available gas was admitted to the ionisation chamber. A series of values of the current was found corresponding to different applied electric fields. Then, leaving the distance between the plates unaltered, part of the gas was removed, thereby lowering the pressure to about three-quarters of its original value, and another series of currents were measured. This was repeated until a sufficient range of pressures had been used. Then the distance *c* to *a* was altered and a similar set of readings taken; and this procedure was repeated until sufficient data had been obtained.

The final series of observations were obtained in a similar manner, with the exception of the interchange of the order of changing pressure and distance.

In order to obtain a measure of the current passing between the electrodes, the earth connection with the electrode system was broken and the time of deflection of the electrometer needle over a certain angle was found. The reading was generally repeated several times, and the average of the observed times of deflection taken in order to eliminate the effects of small irregularities, especially when measuring very small or very large currents. For each value of the pressure and electrode distance potentials were used over the whole range for which it was possible to measure the current. This range was extended to an important degree by the use of the condenser, which reduced the deflections for large currents to readable values.

By this means the readings for the lowest fields usually corresponded to saturation currents, while the highest potentials used approached the neighbourhood of the sparking potentials.

A comparison with the work of Townsend will show that he followed a somewhat different experimental method. In his experiments he measured the currents by a null method instead of by a deflection method. He also adjusted the pressure of the gas and distance of the electrodes to some previously determined values which admitted of comparatively direct solution for α [illegible]. The present method, which is more general, requires a much larger number of readings and a different method of solution (see below).

OBSERVATIONS.

From the time and angle of deflection in each case the rate of deflection (which measured the current) was determined in consistent arbitrary units, taking into account (1) the gradually changing sensitiveness of the electrometer, (2) the capacity of the electrode system. The values of the current so obtained are shown in Table I for (1) a typical set of observations for the preliminary series, (2) the various sets of observations in the final series for helium and for argon. In these tables the currents are given at leading potential intervals; the results are omitted for a number of small potential intervals which were necessarily used in feeling the way toward the higher potentials.

The same results in a slightly modified form are represented graphically by means of sets of Current-Potential Curves (Curves I). In these curves the various currents for the higher potentials are expressed in terms of the corresponding saturation currents, i.e., in the case of each curve the saturation value of the current was taken as the unit of current. Also, instead of using direct potential values as abscissae, the corresponding values of $\frac{X}{p}$ (electric field per unit pressure) were used. Further, on account of the very great range of the values of the current, the curves are plotted on a semi-logarithmic scale, the ordinates being really the logarithms of numbers. In order to exhibit the relative accuracy of the observations, all the co-ordinates are marked in the cases of a few of the curves, different symbols being used to differentiate the various sets.

TABLE I.[1]

CURRENTS. (Arbitrary scale.)

Gas, Helium. Set b. a = .8 cms.

(PRELIMINARY EXPERIMENT.)

Series	B_1	B_2	B_3	B_4	B_5	B_6	B_7
Pressure.	3.50	9.26	11.83	32.599	42.62	56.61	72.22
Potential							
40	....	....	....	.038	.003	.072	.092
80	....	....	.054	.048	.07	.085	.092
120	....	.080	.115	.079	.1	.098	.102
160	.064	.22	.32	.178	.21	.166	.14
200	.16	5.05	.72	.48	.53	.4	.285
206	....	....	12.7				
210	.21	32.4	64.3				
214	....	37.45					
220	.39						
230	1.25						
240	28.						
280		....	....	1.35	1.6	1.13	.74
300	....	....	....	5.7	7.75	4.	2.29
320	....	....	....	13.5	14.1		
340	....	....	....	78.7	150.	25.9	8.4
	....	....	....	....	....	....	21.7

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[1] In these tables and the following curves the units used are: for potential, volts; for distance, centimetres; for pressures, the equivalent of millimetres of mercury.

Gas, Helium. Set a. $p = 104.8$.

Series	a, 1	a, 2	a, 3	a, 4	a, 5
Distance *a*	1.8	1.4	1.0	.7	.4
Potential					
40	.476	.402	.31	.216	.143
80	.492	.409	.305	.222	.146
160	.482	.412	.318	.237	.266
240	.495	.412	.338	.402	.785
280	.49	.396	.379	.816	5.5
320	.486	.431	.566	1.95	10X1.15
340	....	....	....	3.41	10X3.26
360	.504	.478	.96	6.65	
400	.528	.564	2.13	10X2.58	
440	.56	.802	5.57		
480	.658	1.44	10X2.28		
500	....	....	10X5.71		
520	.89	3.115			
560	1.2	8.55			
600	2.14	10X2.84			
610	....	10X4.61			
680	10X1.1				
760	10^2X2.				

Gas, Helium. Set b. $p = 85$

Series	b, 1	b, 2	b, 3	b, 4	b, 5	b, 6	b, 7
Distance *a*	1.8	1.3	.9	.6	.4	.3	.2
Potential							
20	.....	.....	.....	.....	.143	.202	.158
40	.495	.352	.268	.187	.143	.199	.122
120	.524	.37	.271	.218	.244	....	.273
200	.473	.395	.29	.466	1.03	1.47	1.535
240	.479	.383	.43	1.09	3.22	4.55	5.29
260	.....	.....	.....	.....	6.37	.....	10X1.19
280	.475	.41	.77	3.4	10X1.205	10X2.22	10X6.1
300	.....	.....	1.105	6.53	10X2.73		
320	.455	.531	1.72	10X1.285			
340	.....	.....	3.09	10X2.92			
360	.482	.823	5.44	10X8.33			
400	.572	1.67	10X2.33				
420	.....	.....	10X6.				
440	.93	4.36					
480	1.36	10X1.37					
500	.....	10X2.83					
520	2.73	10X6.67					
600	10X1.92						
640	10X7.14						

Gas, Helium. Set c. $p=65.8$.

Series	c, 1	c, 2	c, 3	c, 4	c, 5
Distance *a*	1.4	1.0	.7	.5	.3
Potential					
20	....	....	....	.115	
40	.36	.227	.176	.128	.117
120	.34	.234	.204	.24	.338
200	.354	.387	.865	1.735	2.41
240	.435	.904	3.17	7.27	10×1.373
270	....	....	....	10×2.39	$10^2\times1.48$
280	.668	2.65	10×1.225	10×4.17	
300	....	....	10×2.77	$10^2\times1.89$	
320	1.52	10×1.04	10×8.25		
340	....	10×2.13	$10^2\times4.56$		
360	4.83	10×6.85			
400	10×1.95				
420	10×3.91				

Gas, Helium. Set d. $p=46.5$.

Series	d, 1	d, 2	d, 3	d, 4	d, 5	d, 6	d, 7
Distance *a*	1.8	1.3	.9	.6	.4	.3	.2
Potential							
20	....	....	....	....	....	.061	.054
40	.242	.257	.15	.109	.103	.065	.055
120	.239	.232	.142	.144	.17	....	.177
200	.232	.284	.31	.603	1.02	1.06	.938
240	.242	.321	.65	1.77	2.9	3.1	5.
260	....	....	....	....	....	7.1	$10^2\times1.$
280	.282	.532	1.78	6.38	10×1.21	10×2.83	
290	....	....	....	....	10×2.11	$10^2\times1.$	
310	....	....	....	....	$10^2\times1.$		
320	.362	1.045	6.0	10×2.96			
360	.525	2.81	10×2.17				
400	1.084	9.58	$10^2\times3.$				
440	2.54	10×4.54					
480	7.02	$10^2\times7.299$					
490	....	$10^3\times5.22$					
500	10×1.22						
520	10×2.46						
560	$10^2\times1.03$						
580	$10^2\times3.96$						
600	$10^3\times3.47$						
610	$10^4\times2.04$						

Gas, Helium. Set e. $p=25.43$.

Series	e, 1	e, 2	e, 3	e, 4	e, 5	e, 6	e, 7
Distance *a*	1.8	1.3	.9	.6	.41	.3	.2
Potential							
20	....	....	....	....	.049	.036	.031
40	.131	.102	.095	.077	.049	.041	.047
120	.137	.118	.122	.144	.131	.114	.111
200	.195	.289	.529	.819	.71	.601	.367
240	.334	.651	1.47	2.14	2.61	2.62	6.3
260	....	....	....	....	4.83	$10^{2}\times3.16$	$10^{4}\times1.1$
280	.714	1.84	4.76	8.5	$10^{2}\times1.46$	$10^{4}\times4.1$	$10^{7}\times1.68$
300	....	....	9.75	10×2.67	$10^{4}\times3.42$	$10^{6}\times4.66$	
320	1.76	6.25	10×2.72	$10^{3}\times1.324$	$10^{6}\times4.33$		
340	....	....	$10^{2}\times1.165$	$10^{4}\times6.66$			
360	6.06	10×3.15	$10^{3}\times4.62$				
380	10×1.13	$10^{2}\times1.24$	$10^{5}\times1.665$				
400	10×2.53	$10^{3}\times5.42$	$10^{6}\times7.8$				
420	10×6.65	$10^{6}\times1.3$					
430	$10^{2}\times1.39$	$10^{6}\times5.38$					
460	$10^{4}\times1.215$						

Gas, Helium. Set f. $p=13.65$.

Series	f, 1	f, 2	f, 3	f, 4	f, 5	f, 6	f, 7
Distance *a*	1.9	1.3	.9	.6	.4	.3	.2
Potential							
20	....	....	....	....	....	.025	.065
40	.1	.067	.062	.05	.039	.036	.061
120	.092	.094	.123	.103	.093	.078	.103
200	.155	.250	.468	.45	.373	.276	.206
240	.29	.578	1.11	1.22	1.47	1.68	.633
260	....	....	....	2.27	10×3.21	$10^{3}\times1.2$	$10^{4}\times1.03$
280	.627	1.61	3.48	9.27	$10^{4}\times1.66$	$10^{4}\times4.75$	$10^{4}\times3.47$
300	....	....	7.6	$10^{3}\times4.5$	$10^{6}\times2.49$	$10^{5}\times4.67$	
310	....	....	....	$10^{4}\times3.39$	$10^{6}\times7.8$		
320	1.66	5.34	10×2.58	$10^{5}\times1.4$			
330	....	7.82	....	$10^{5}\times4.87$			
360	5.42	10×2.98	$10^{4}\times7.8$				
400	10×2.5	$10^{4}\times2.4$					
420	$10^{2}\times1.36$	$10^{5}\times4.21$					
430	....	$10^{5}\times7.8$					
460	$10^{5}\times1.69$						

Gas, Helium. Set g. $p = 9.01$.

Series	g, 1	g, 2	g, 3	g, 4	g, 5	g, 6
Distance *a*	1.8	1.3	.9	.6	.4	.3
Potential						
20	.061	.054	.05	.04	.039	.037
40	.057	.057	.042	.047	.058	.038
120	.169	.065	.149	.11	.081	.067
200	1.33	1.1	.806	.538	.303	.196
240	5.07	4.53	10×1.28	10×2.84	10×7.67	8.1
260	10×1.08	....	$10^3 \times 5.67$	$10^4 \times 1.3$	$10^4 \times 2.36$	$10^4 \times 1.1$
270	....	....	$10^4 \times 3.6$	$10^4 \times 5.4$	$10^4 \times 7.8$	$10^4 \times 4.9$
280	....	$10^3 \times 3.\ 2$	$10^5 \times 1.3$	$10^5 \times 1.86$	$10^5 \times 2.85$	$10^6 \times 1.56$
290	....	....	$10^5 \times 4.87$	$10^5 \times 6.$		
310	$10^4 \times 4.54$	$10^6 \times 5.$				

Gas, Helium, Set h. $p = 5.69$.

Series	h, 1	h, 2	h, 3	h, 4	h, 5	h, 6
Distance *a*	1.8	1.3	.9	.6	.4	.3
Potential						
20	.057	.058	.101			
40	.055	.054	.127	.038	.031	.028
120	.098	.071	.17	.102	.056	.045
200	.441	.467	.454	.502	.382	.136
220	....	.708	1.02	10×2.25	$10^2 \times 2.45$	10×7.9
230	....	.976	2.34	$10^3 \times 2.32$	$10^3 \times 6.49$	
240	1.11	1.33	10×2.5	$10^4 \times 1.8$	$10^4 \times 1.88$	
250	....	1.87	$10^3 \times 1.76$	$10^4 \times 7.29$		
260	1.92	3.02	$10^4 \times 1.6$	$10^5 \times 2\ 16$		
280	3.7	10×4.98	$10^6 \times 2.38$			
300	10×1.13	$10^4 \times 1.1$				
320	$10^2 \times 2.8$	$10^6 \times 2.04$				
340	$10^4 \times 3.77$					
360	$10^6 \times 6.$					

Gas, Helium. Set 1. $p=3.35$.

Series	i, 1	i, 2	i, 3	i, 4	i, 5
Distance a	1.8	1.3	.9	.6	.4
Potential					
20	.067	.052			
40	.054	.045	.033	.04	.099
120	.11	.082	.069	.059	.11
200	.39	.279	.186	.122	.114
240	1.15	.922	.672	.259	.131
260	2.69	9.9	10×2.41	.584	
270	10×1.13	10^2×3.28	10^3×1.98	6.55	.16
290	10^3×7.3	10^4×4.28	10^4×8.2	10^4×1.4	.31
300	10^4×4.3	10^5×1.34	10^5×3.	.....	10×2.7
310	10^5×1.53	10^6×3.9	.....	.....	10^2×5.48

Gas. Argon. Set I. $p=17.75$.

Series	I, 1	I, 2	I, 3	I, 4	I, 5
Distance a	1.8	1.0	.6	.4	.2
Potential					
40	.475	.32	.211	.120	.077
120	.52	.....	.247	.178	.154
200	.538	....	.337	.375	537
280	.596	.....	.698	1.39	10×1.28
320	.....	.626	1.12	3.64	10^4×6.25
400	.....	1.12	5.75	10^4×1.76	
420	.....	.....	.....	10^5×1.9	
440	.833	1.84	10×3.1		
470	.....	.....	10^3×2.68		
480	.....	3.38	10^4×1.13		
520	1.16	7.05			
600	1.62	10^2×2.14			
760	10×1.38				
800	10×3.4				
840	10^2×3.31				

Gas, Argon. Set II. p=9.71.

Series	II, 1	II, 2	II, 3	II, 4	II, 5
Distance *a*	1.8	1.0	.6	.4	.2
Potential					
40	.255	.155	.103	.071	.051
120	.....	.197	.143	.129	.13
200	.....	.282	.322	.445	.72
240	.365	.....	.633	1.	10^2x9.3
260	.....	.....	.....	.....	10^4x6.96
280	.....	.652	1.46	4.	
300	.....	.....	.....	10x1.67	
320	.524	1.11	3.5	10^3x5.8	
360	.....	2.31	10^2x1.26		
400	1.03	6.85			
440	.....	10x7.7			
560	10x2.				
600	10^2x2.				
620	10^3x3.37				

Gas, Argon. Set III. p=5.37.

Series	III, 1	III, 2	III, 3	III, 4	III, 5
Distance *a*	1.8	1.0	.6	.4	.2
Potential					
40	.114	.114	.088	.082	.061
120	.165	.151	.146	.135	
200	.....	.316	.451	.588	3.23
230	.....	.....	.....	.....	10^4x6.37
240	.31	.....	1.19	3.97	
270	.....	.....	.....	10^4x6.1	
280	.....	1.34	6.45		
320	.793	4.04	10^4x3.8		
360	1.44	10x8.9			
440	9.4				
480	10x5.7				

Gas, Argon. Set IV. $p = 2.94$.

Series	IV, 1	IV, 2	IV, 3	IV, 4
40	.083	.056	.042	.053
200	.237	.352	.508	.84
230	.....	.....	.....	$10^3 \times 7.35$
240	.....	.844	6.53	$10^4 \times 4.7$
280	.902	3.39	$10^5 \times 1.44$	
320	2.37	$10^3 \times 4.7$		
360	10×1.1			
400	$10^3 \times 3.16$			

INDEX TO CURRENT-POTENTIAL CURVES.

1. *Gas, Helium. (Preliminary Experiments.)*

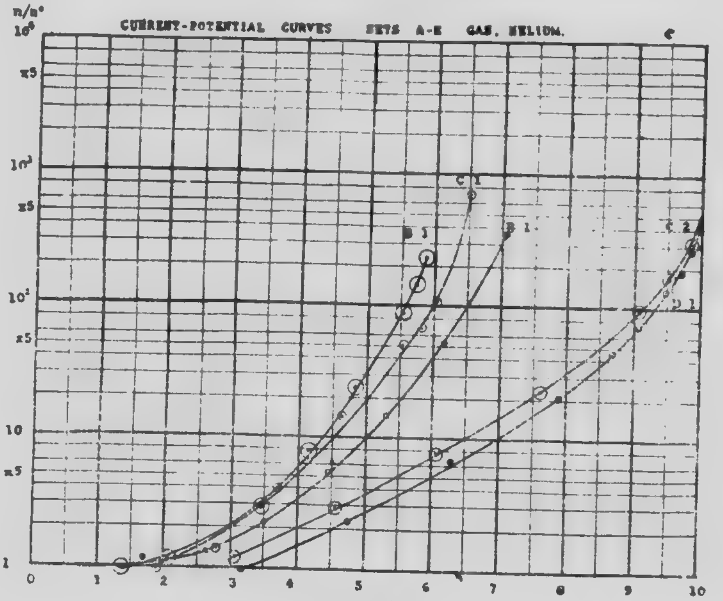
a	p	Series	Page	p	Series	Page	p	Series	Page
1.2	62.67	A 1	27	38.06	A 2	27	20	A 3	27
1.2	10.39	A 4	27						
.8	72.22	B 1	26	56.61	B 2	26	41.62	B 3	27
.8	32.59	B 4	27	11.82	B 5	27	9.26	B 6	27
.8	3.50	B 7	27						
.6	70.17	C 1	26	43.9	C 2	26	27.28	C 4	27
.6	21.1	C 5	27	16.3	C 6	27	13.	C 7	27
.6	10.28	C 8	27	8.13	C 9	27	6.38	C 10	27
.6	5.1	C 11	28	3.1	C 12	28			
.4	63.15	D 1	26	43.36	D 2	27	24.48	D 4	27
.4	14.85	D 5	27–8	9.24	D 6	27–8	5.9	D 7	28
.2	63.1	E 1	27	23.49	E 3	27	12.17	E 4	28
.2	6.25	E 5	28						

2. *Gas, Argon.*

p	a	Series	a	Series	a	Series	a	Series	Page
17.75	1.8	I 1	1.0	I 2	.6	I 3	.4	I 4	33
17.75	.2	I 5							33
9.71	1.8	II 1	1.0	II 2	.6	II 3	.4	II 4	33
9.71	.2	II 5							33
5.37	1.8	III 1	1.0	III 2	.6	III 3	.4	III 4	34
5.37	.2	III 5							34
2.94	1.8	IV 1	1.0	IV 2	.6	IV 3	.4	IV 4	34

3. *Gas, Helium.*

p	a	Series	a	Series	a	Series	a	Series	Page
104.8	1.8	a 1	1.4	a 2	1.0	a 3	.7	a 4	28
104.8	.4	a 5							28
85	1.8	b 1	1.3	b 2	.9	b 3	.6	b 4	29
85	.4	b 5	.3	b 6	.2	b 7			29
65.8	1.4	c 1	1.0	c 2	.7	c 3	.5	c 4	29
65.8	.3	c 5	.2	c 6					29
46.5	1.8	d 1	1.3	d 2	.9	d 3	.6	d 4	30
46.5	.4	d 5	.3	d 6	.2	d 7			30
25.43	1.8	e 1	1.3	e 2	.9	e 3	.6	e 5	30
25.43	.41	e 5	.3	e 6	.2	e 7			30
13.65	1.9	f 1	1.3	f 2	.9	f 3	.6	f 4	31
13.65	.4	f 5	.3	f 6	.2	f 7			31
9.01	1.8	g 1	1.3	g 2	.9	g 3	.6	g 4	31
9.01	.4	g 5	.3	g 6					31
5.69	1.8	h 1	1.3	h 2	.9	h 3	.6	h 4	32
5.69	.4	h 5	.3	h 6					32
3.35	1.8	i 1	1.3	i 2	.9	i 3	.6	i 4	32
3.35	.4	i 5							32



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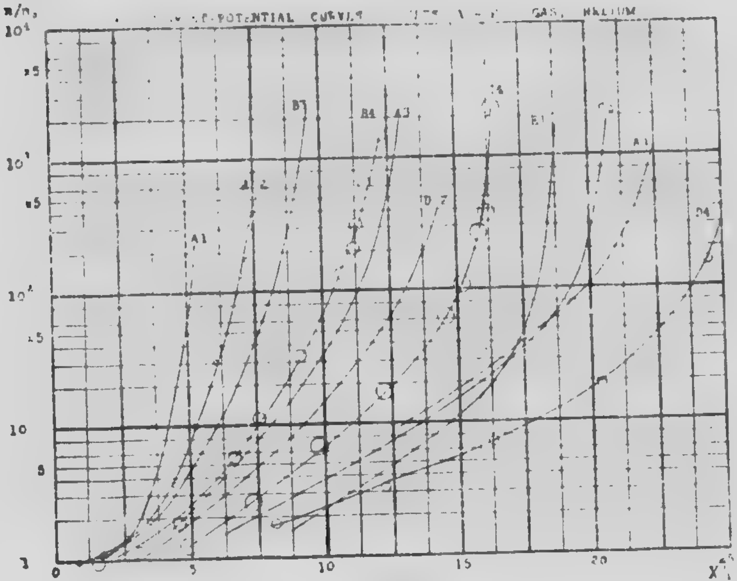

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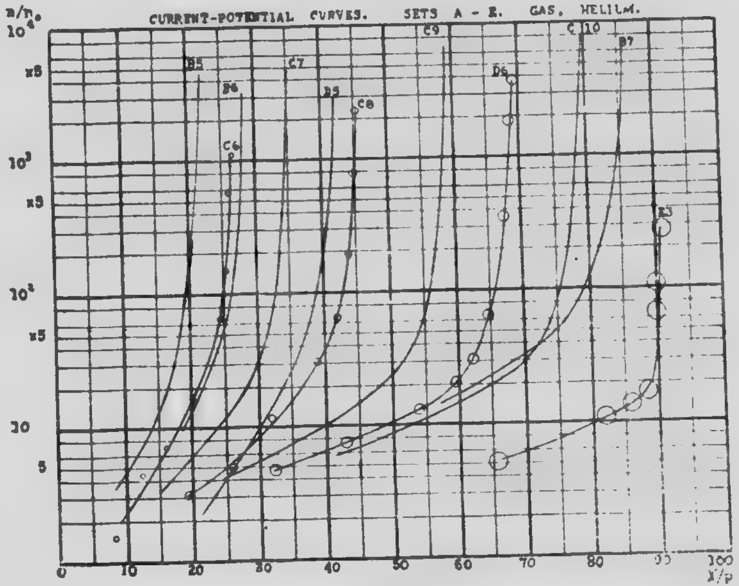

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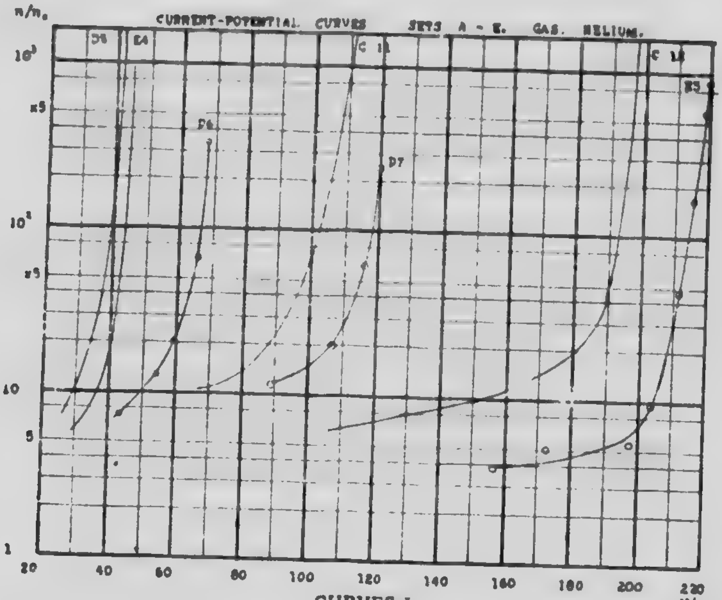

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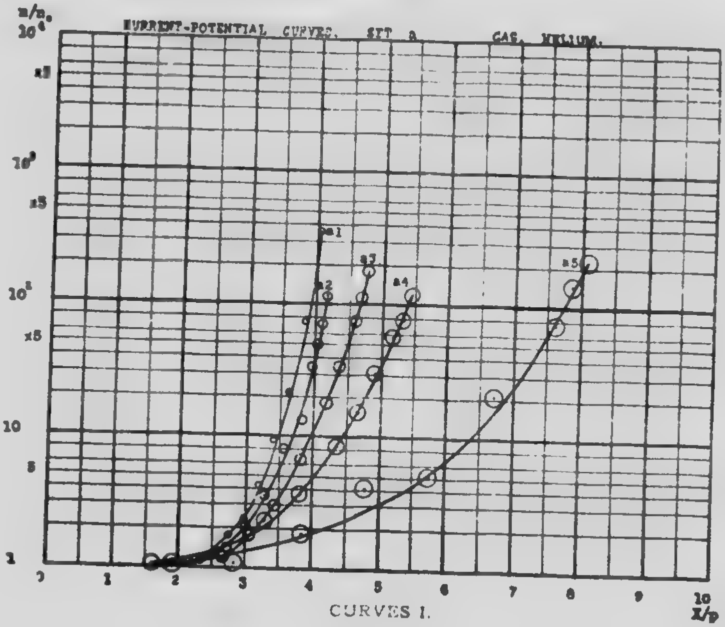

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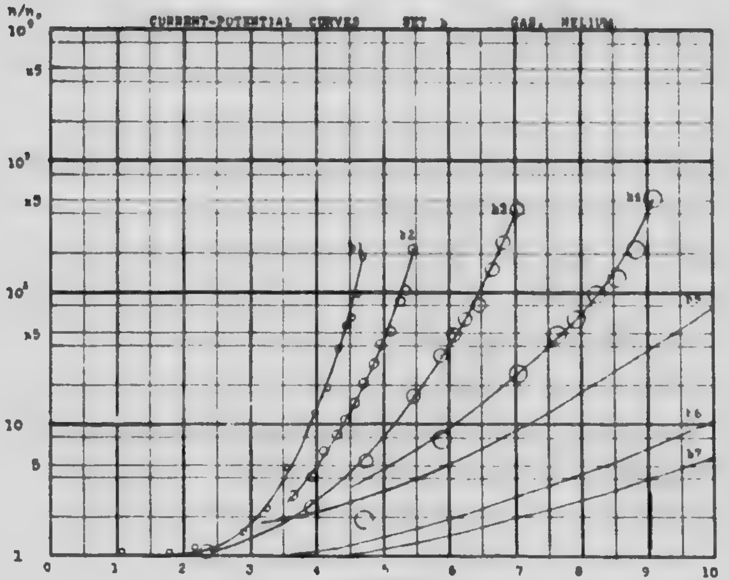

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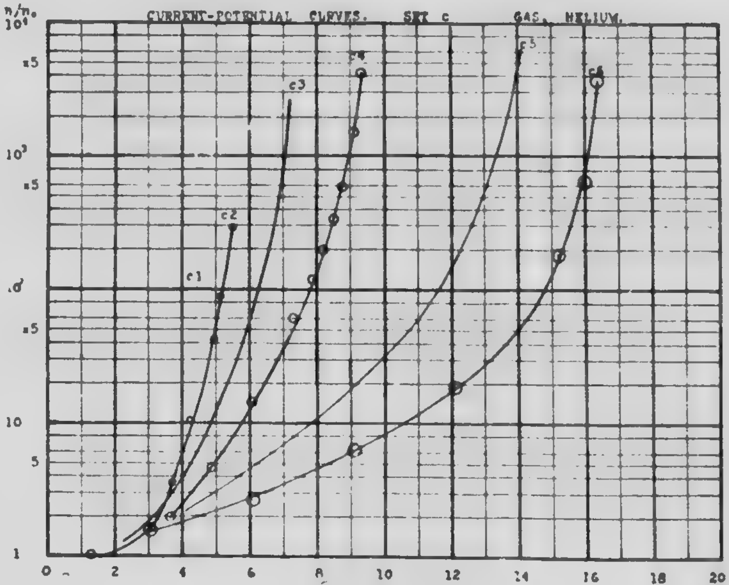

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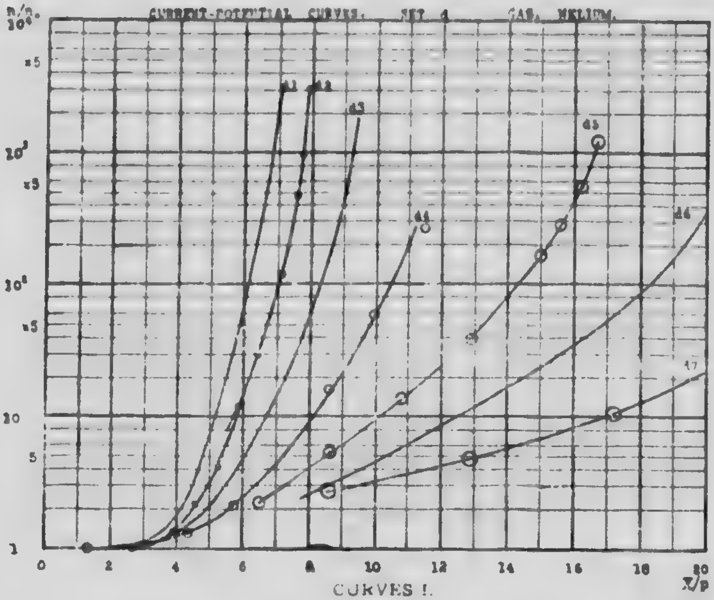

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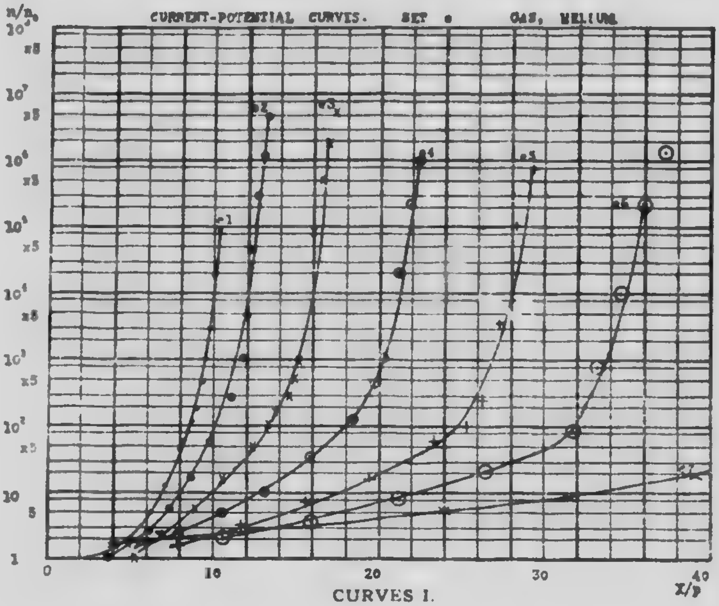

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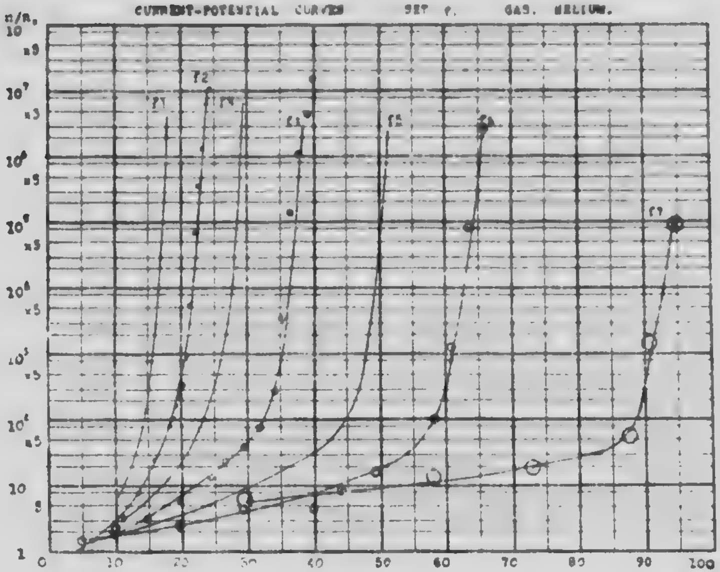

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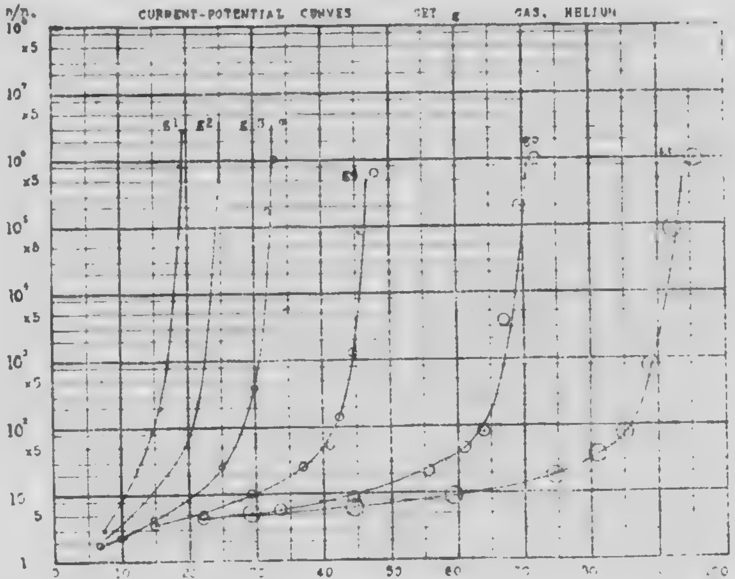

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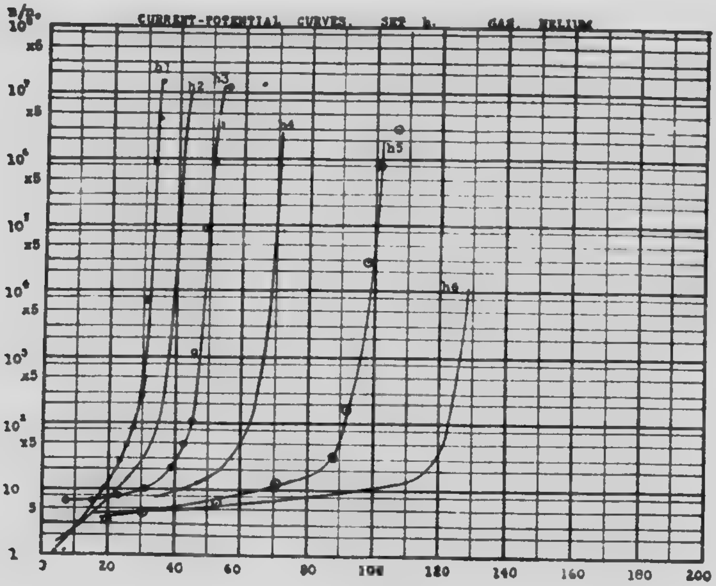

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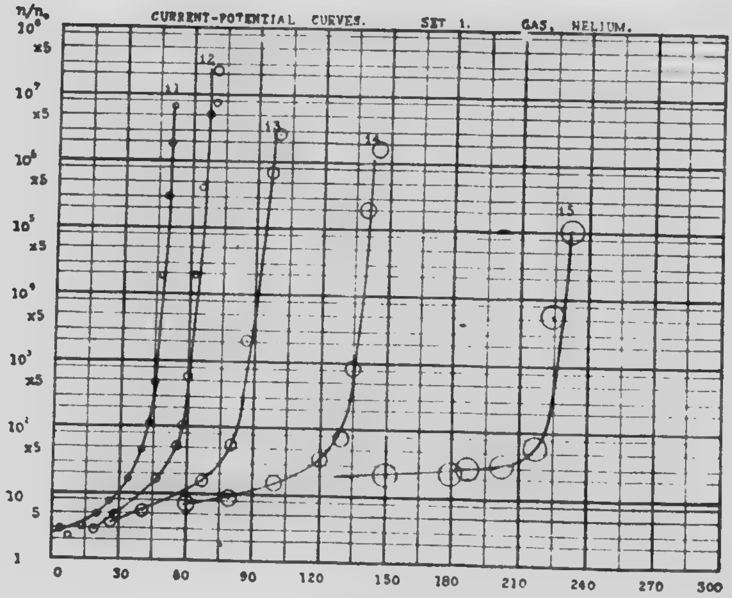

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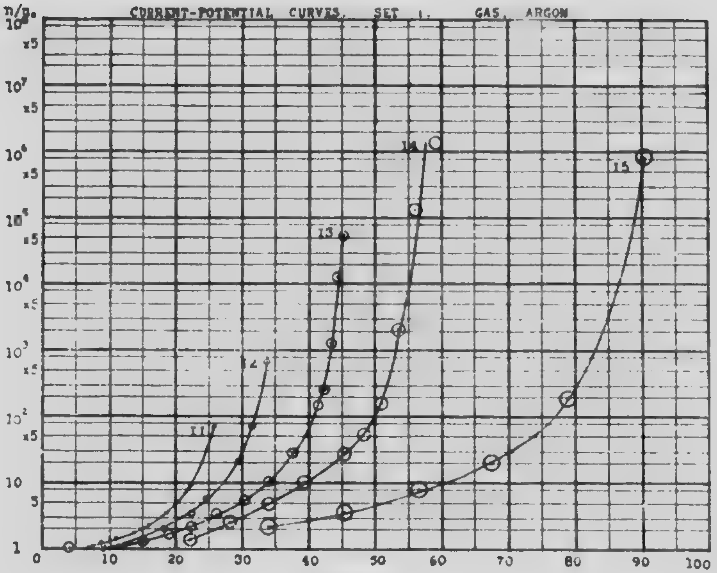

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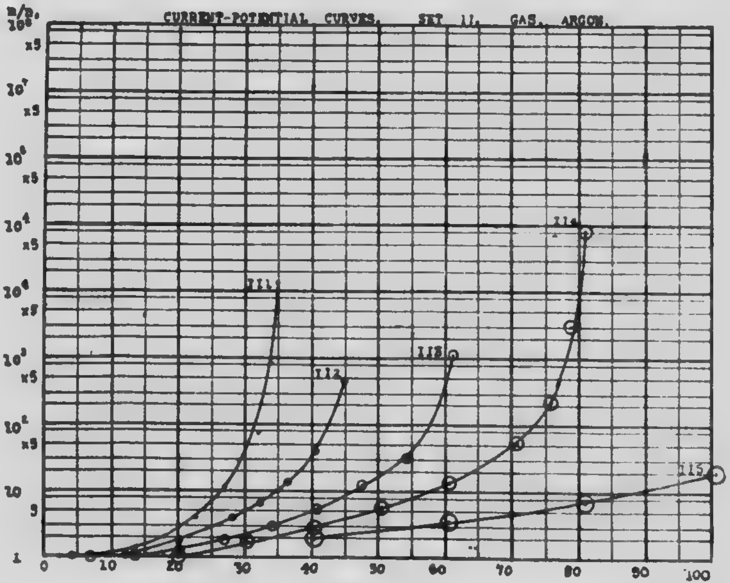

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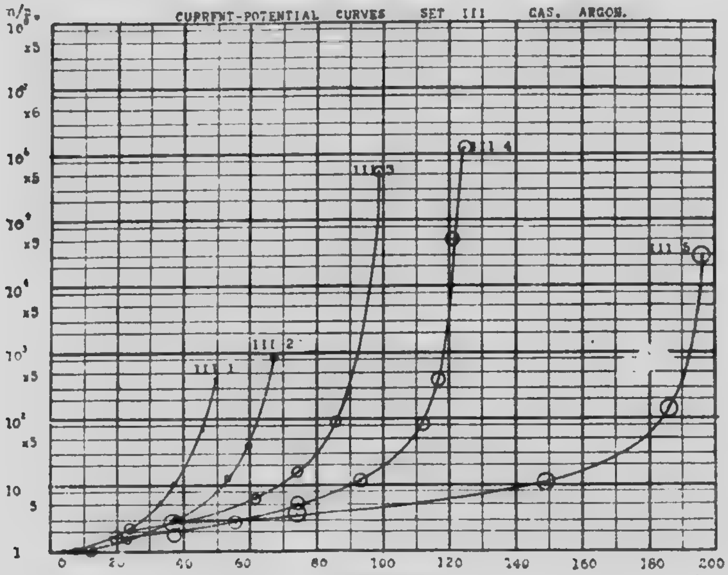

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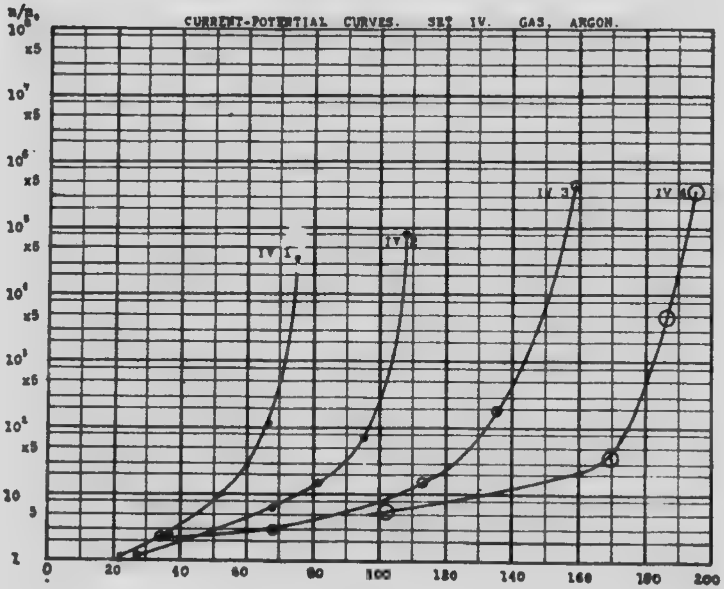
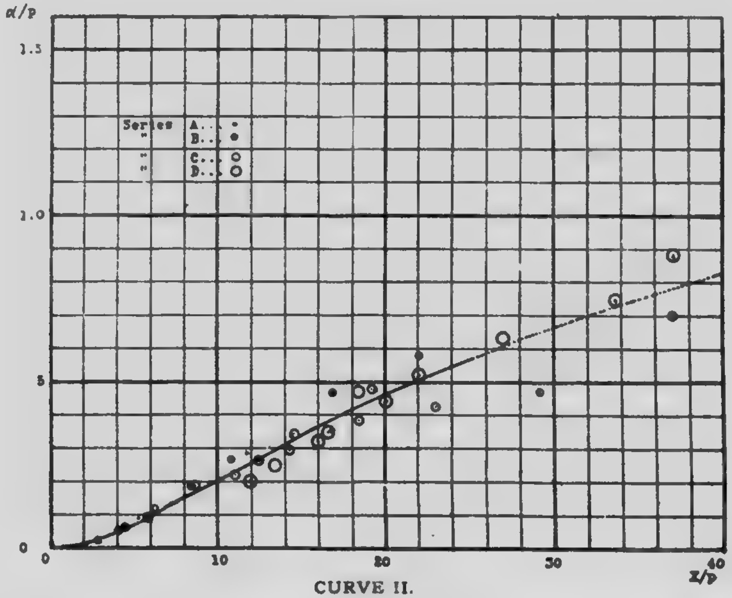


CURVES I.

REDUCTION OF OBSERVATIONS.

I. The preliminary set of observations was used to calculate a series of values of α on the assumption that the values of β were so small that they could be neglected. On this assumption the formula for $\frac{n}{n_0}$, as given on page 6, becomes

$$\frac{n}{n_0} = \frac{e^{\alpha a} - 1}{\alpha a}.$$



CURVE II.

From the experimental values of $\frac{n}{n_0}$ and of a the values of α were determined by means of a graphical method. This method consisted in plotting the curve,

$$y = \frac{e^x - 1}{x}$$

on a semi-logarithmic scale, and in finding from this curve the values of x corresponding to the several values, $\frac{n}{n_0}$, of y. The corresponding values of $\frac{x}{a}$ were then the corresponding values of α.

The values of α obtained from these experiments are shown in Table II, and the values of $\frac{\alpha}{p}$ are plotted against $\frac{X}{p}$ in Curve II, page 35. It will be seen from this curve that when $\frac{X}{p}$ is small the values obtained from the various observations form a fairly continuous curve, as should be expected from theoretical considerations (page 7). On the other hand, for the higher values of $\frac{X}{p}$ the values of $\frac{\alpha}{p}$ diverge considerably from the position of the curve, so that for these values it was apparently not permissible to neglect β in following the method used to estimate α.

TABLE II.

VALUES OF α FOR HELIUM.

(PRELIMINARY EXPERIMENTS.)

Series	Field	α	Field	α	Field	α	Field	α	Field	α
A 1	150	3.5	200	5.	225	6.4	230	7		
A 2	150	3	200	4.5	225	5.9	250	7.2		
A 3	150	1.5	200	2.96	250	4.8	275	5.3		
A 4	150	.44	200	.98	250	2.5	300	4.37	340	6.12
B 1	200	5	250	6.5	275	7.8				
B 2	200	5.45	250	9.5	262.5	12.4				
B 3	200	5.7	250	10.1	262.5	13.1				
B 4	200	3	250	4.63	300	6.4	350	8.4	400	12.2
B 5	200	2.84	250	4.53	300	6.25	350	8.2	400	13.5
B 6	200	1.8	250	3.4	300	5.3	350	7.2	400	9.9
B 7	200	.96	300	4.25	350	5.9	400	8	425	9.3
C 1	200	1.2	300	5.5	400	9.35	425	6.1	450	6.4
C 2	200	2.8	300	6.4	400	10.7	425	12.3		
C 3	200	3.2	300	6.67	400	11.4				
C 4			300	6.1	400	10	425	13	450	16.6
C 5	200	3.6	300	6.1	400	10.25	425	14.2		
C 6	200	4.1	300	6	400	10	425	13.1		
C 7	300	5.6	400	8.75	425	14.75				
C 8	300	5.55	400	8.4	425	9.5	450	12.1	465	16.2
C 9	300	5.63	400	7.8	450	10.25	475	16.95		
C 10	300	5.5	400	7	450	8.4	475	9.7		

Series	Field	α	Field	α	Field	α	Field	α	Field	α
C 11	450	7.52	500	9.23	525	16.1				
C 12	550	7.6	600	11.7	615	16.5				
D 1	400	7.3	500	11.45	600	17	625	17.9		
D 2	400	7.22	500	11.8	550	14.55	600	21.7		
D 3	300	5	500	11.1	550	13.1	600	16.7	625	21.1
G 4	400	9.4	500	11.3	550	13.15	600	19	625	24.3
D 5	400	7.93	500	9.8	550	11.4	600	14.9	625	19.8
D 6	500	9.45	600	11.3	675	18.7				
E 1	700	9.2	800	13	900	16.1	1000	20	1150	34.1
E 2	700	7.8	800	13	900	17	1000	25.8	1050	41.7
E 3	700	11.2	800	14.8	900	19.4	1000	27.7	1050	44.8
E 4	800	13.6	900	15.6	1000	18	1050	20	1120	39.6
E 5	1300	17.8	1400	44.8						

2. For the final sets of results a general method of solution was devised by which α and β were simultaneously evaluated. This method requires the assumption that $\frac{\alpha}{p}$ and $\frac{\beta}{p}$ are constants for a constant value of $\frac{X}{p}$ and varying distances between the electrodes. Thus:

From page 6 we have

$$\frac{n_0}{n} = \frac{a\{\alpha - \beta e^{(\alpha-\beta)a}\}}{e^{(\alpha-\beta)a} - 1},$$

which may be written

$$\beta a = \frac{(\alpha-\beta)a}{e^{(\alpha-\beta)a} - 1} - \frac{n_0}{n}$$

or

$$y = \frac{x}{e^{apx} - 1} - \frac{n_0}{apn}$$

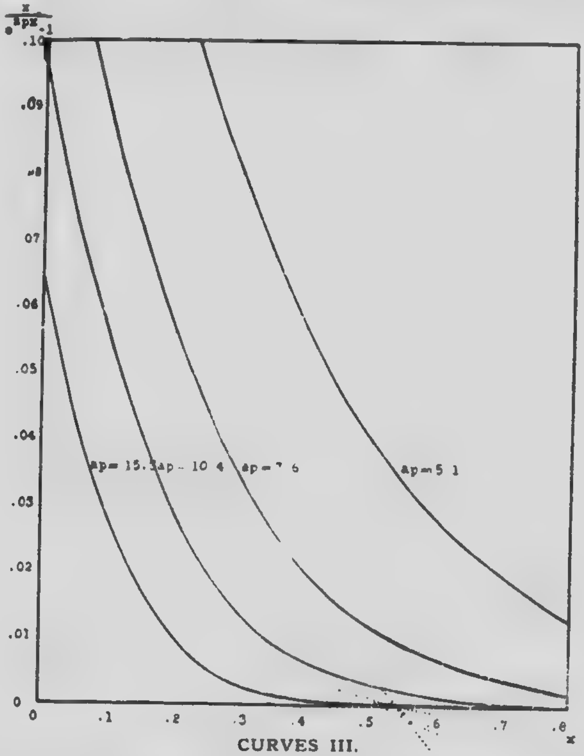
where $y = \frac{\beta}{p}$, $x = \frac{(\alpha-\beta)}{p}$.

This equation gives a method of solving for x and y, and hence for α and β. For, if $a, p, \frac{n}{n_0}$ and $a', p', \frac{n'}{n'_0}$ are known to give simultaneous values of α and β, the corresponding values of x and y are the co-ordinates of the point of intersection of the curves,

$$y = \frac{x}{e^{apx} - 1} - \frac{n_0}{apn} \quad \text{and} \quad y = \frac{x}{e^{a'p'x} - 1} - \frac{n'_0}{n'p'a'}.$$

The method of solution may be explained by considering a specific example, viz., the determination of x and y corresponding to the value $\frac{X}{p} = 23.5$ from the data made at the pressure 25.43 (in helium).

First, the curves, $y = \frac{x}{e^{apx} - 1}$, were plotted, one for each of the values of ap (15.3, 10.4, 7.6, 5.1) for which the current corresponding to $\frac{X}{p} = 23.5$ had been found (Curves III, above). Then for each curve and for the selected value of $\frac{X}{p}$ the value of $\frac{n}{n_0}$ is found by reference to the Current-Potential Curve II, and thence the value of $\frac{n_0}{apn}$ (respectively 0, .001, .011, .035). Each curve was



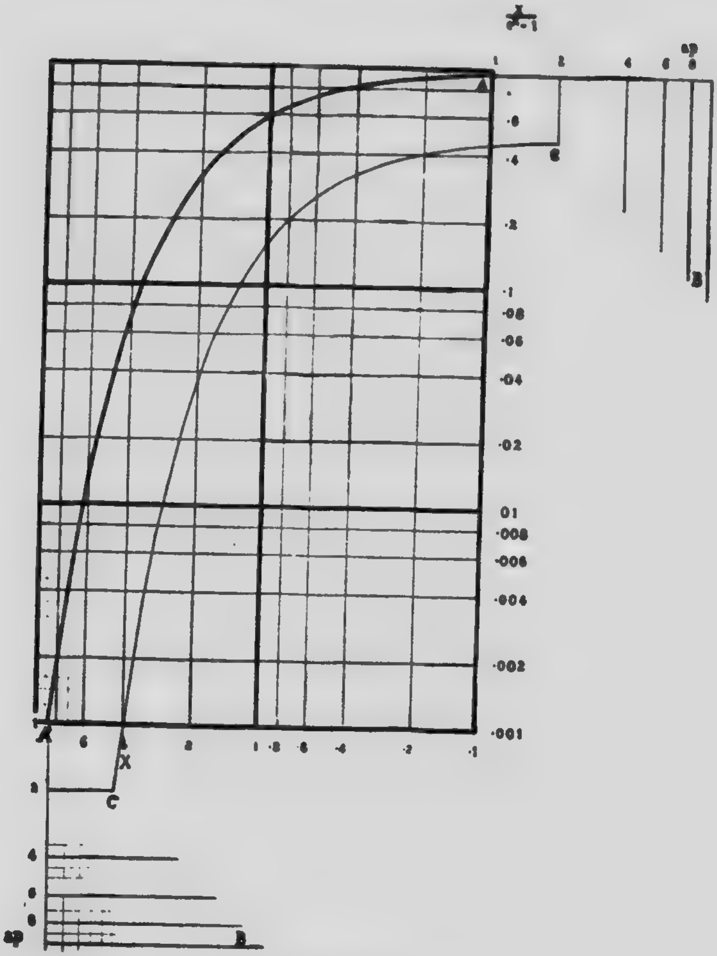
CURVES III.

then moved parallel to itself in the direction YO through the distance $\frac{n_0}{apn}$, thus giving the curves

$$y = \frac{x}{e^{apx} - 1} - \frac{n_0}{apn}.$$

These are indicated in the Curves III by the dotted lines, only a small part being shown, as only the point of intersection of these curves was wanted. The co-ordinates of the various points of intersection were then found and averaged, giving, in the example, for x, 5.25, and for y, about .0001.

Sets of co-ordinates for plotting the curves $y = \frac{x}{e^{apx} - 1}$ were calculated mechanically by use of the auxiliary curve $y = \frac{x}{e^x - 1}$ plotted in logarithmic co-ordinates. It is obvious that if (x, y) is a point on the curve $y = \frac{x}{e^x - 1}$, then $\frac{x}{ap}, \frac{y}{ap}$ are the co-ordinates of a point on the curve $y = \frac{x}{e^{apx} - 1}$. Pairs of co-ordinates on the latter curve may therefore be found by selecting pairs of co-ordinates on the former and dividing each by ap. If the auxiliary curve is plotted in logarithmic co-ordinates (AA', Curves IV, page 40), any other curve may be derived from it at once on the same scale, by moving it parallel to itself through the distance log. ap toward the origin along *each* axis, or through the distance $\sqrt{2}$ log. ap toward the origin in the direction making an angle of 45° with the axes. In following out the method a mechanical curve was constructed to fit the auxiliary curve. Lines AB, $A'B'$ were drawn, making an angle of 45° with the co-ordinate axes and calibrated in values of ap so that marked points on the mechanical curve could be set at corresponding points on these lines, and the curve ruled in at once. The required sets of co-ordinates for the curve $y = \frac{x}{e^{apx} - 1}$ were then read off directly from the curve. As an example the logarithmic curve for $ap = 2$ is shown (CC') in Curves IV.



CURVES IV.

RESULTS.

Values of x and y for helium and argon deduced by the above method are shown in Table III, page 41. The results are also exhibited graphically in Curves V, page 43. The curves $\left(x, \frac{X}{p}\right)$, $\left(y, \frac{X}{p}\right)$ are plotted for each gas, the latter showing directly the relations between $\frac{\beta}{p}$ and $\frac{X}{p}$. A third curve is plotted from these two with ordinates $x+y$ $\left(\text{equal to } \frac{\alpha}{p}\right)$ showing the relation between $\frac{\alpha}{p}$ and $\frac{X}{p}$.

In order to facilitate comparison between the values of $\frac{\alpha}{p}$ and $\frac{\beta}{p}$ for helium and argon, with their values for other gases (air, hydrogen and carbondioxide) as determined by Townsend, the results for the several gases are collected in Curves VI, pages 43, 44.

TABLE III.

VALUES OF $x=\frac{(\alpha-\beta)}{p}$. HELIUM.

Series	$\frac{X}{p}$	x	$\frac{X}{p}$	x	$\frac{X}{p}$	x	$\frac{X}{p}$	x	$\frac{X}{p}$	x
a	3	.006	5	.05						
b	5	.06	7	.15	10	.19				
d	15	.32	20	.51						
e	10	.17	15	.31	20	.47	25	.59	30	.71
	35	.85	40	.96						
f	20	.43	30	.67	40	.92	50	1.13	60	1.32
	65	1.4	70	1.46						
g	20	.45	30	.68	40	.89	50	1.09	60	1.29
	70	1.44								
h	30	.7	50	1.13	70	1.44	90	1.6		
i	45	.98	60	1.3						
	110	1.9	200	2.4						

VALUES OF $y=\frac{\beta}{p}$. HELIUM.

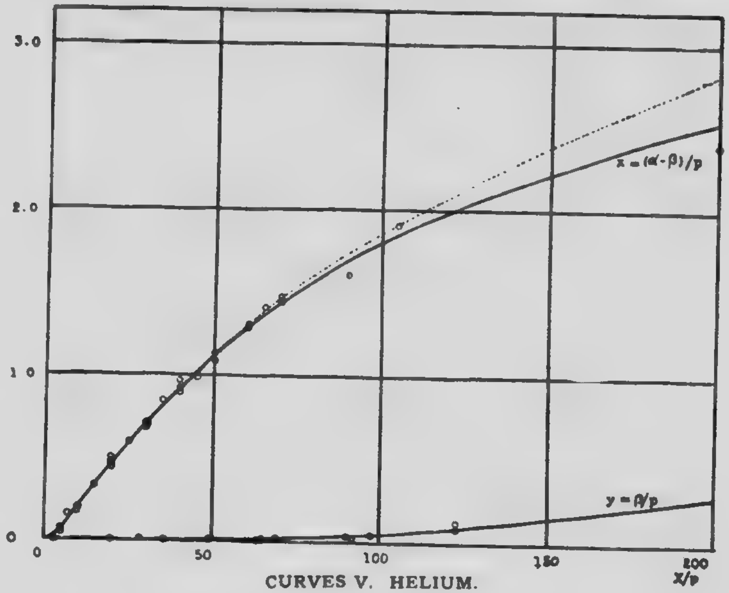
a	8	.0						
b	16.5	.0						
c	120	.02						
d	28	.001						
e	36	.0012	56	.002				
f	49	.002	64	.006	92	.017		
g	69	.011	92	.017				
h	40	.004	65	.014	98	.04	123	.08
i	90	.03	135	.12	225	.303		

VALUES OF $x=\frac{(\alpha-\beta)}{p}$. ARGON.

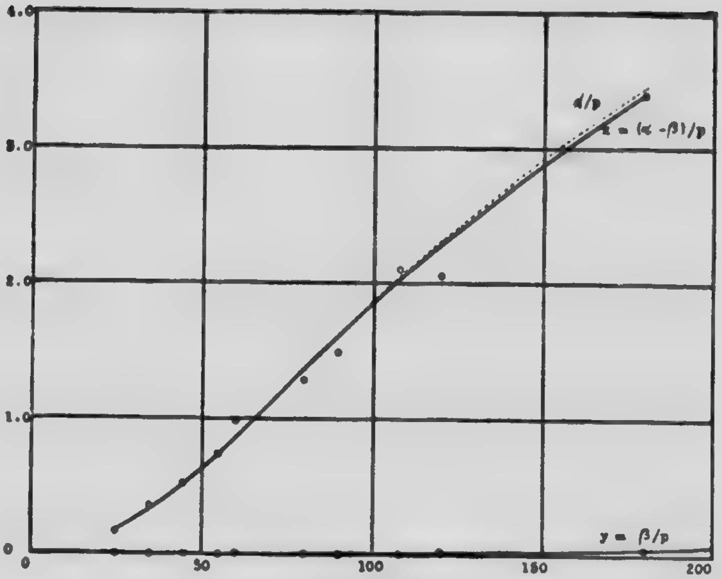
$y=\frac{\beta}{p}$.

$\frac{X}{p}$	25	35	45	55	60	80
x	.155	.368	.52	.773	.98	1.29
y	0	0	.001	.001	.0016	.006

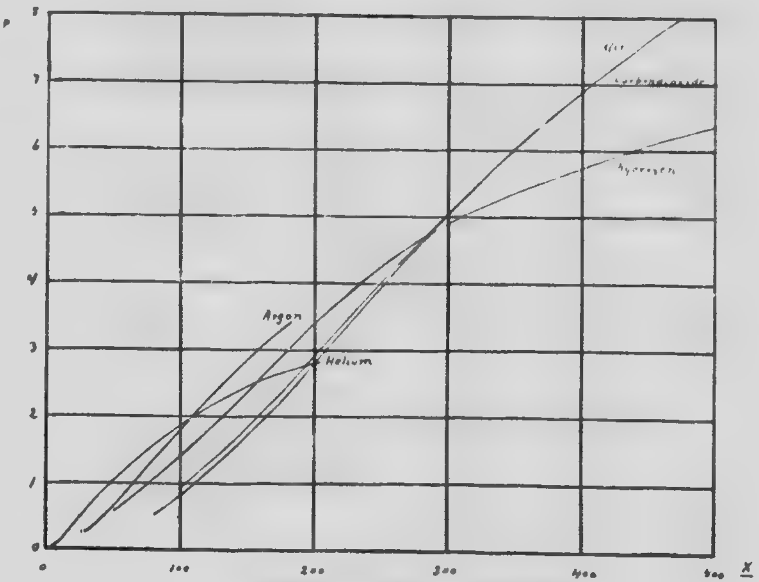
$\frac{X}{p}$	90	108	120	160	180
x	1.49	2.1	2.05	3.1	3.4
y	.007	.011	.03		.047



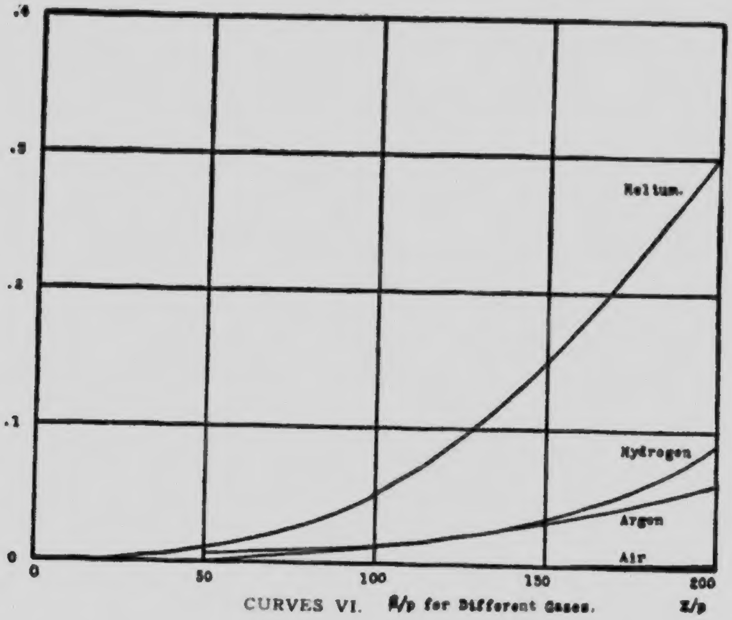
CURVES V. HELIUM.



CURVES V. ARGON.



CURVES VI. d/p for Different Gases.



CURVES VI. α/p for Different Gases.

DISCUSSION OF RESULTS.

The results of the experiments as given in the preceding tables and curves exhibit the characteristics outlined in connection with the theory (pages 5-7). The values of both $\frac{\alpha}{p}$ and $\frac{\beta}{p}$ increase from zero with increasing values of $\frac{X}{p}$ in the way predicted, and further, the Curves V show that the former are continuous functions of the latter.

In comparing the numerical values of $\frac{\alpha}{p}$ and $\frac{\beta}{p}$ for helium and argon with those of the other gases the following points may be noted :—

(1) $\frac{\alpha}{p}$. (See Curves VI.)

In helium, for high pressure $\left(\text{low values of } \frac{X}{p}\right)$ the values of

$\frac{\alpha}{p}$ are much in excess of those of other gases, whereas for higher values of $\frac{X}{p}$ they apparently tend to a lower limit. In argon, on the other hand, though the values are somewhat greater than those of the gases cited, the curve seems to follow the same general form as in these gases.

$\frac{\beta}{p}$. (See Curves VI.)

In the helium, for the range of pressures and potentials used, the values of $\frac{\beta}{p}$ are very much greater than those of other gases under corresponding circumstances. The values for argon lie in the same neighbourhood as those for hydrogen and air.

The large ionising powers of both positive and negative ions in helium are consistent with the high conductivity of the gas at comparatively high pressure and low electric fields. The phenomenon will account also for the low sparking potentials and the low electric fields required to maintain a luminous discharge in the gas at pressures which are high, compared with those in other gases. For, according to Townsend's theory, a luminous discharge takes place, i.e., the current becomes infinite, when $\alpha - \beta e^{(\alpha-\beta)a} = 0$, and this condition will be fulfilled for low electric fields on account of the high values of $\frac{\alpha}{p}$ and $\frac{\beta}{p}$.

(2) The pressure at which $\frac{\alpha}{p}$ is a maximum for a given field X is peculiarly high in helium. This pressure is about $\frac{X}{25}$, since a tangent from the origin to the $\left(\frac{X}{p}, \frac{\alpha}{p}\right)$ curve touches it at the point $\frac{X}{p} = 25$. (See page 8.) The corresponding value of p for argon is $\frac{X}{150}$. Townsend found $\frac{X}{372}$ to be the value for air, and his data give approximately $\frac{X}{190}$ and $\frac{X}{400}$ for hydrogen and carbondioxide respectively.

(3) The energy necessary to ionise a molecule of gas may be estimated by the method explained on page 6. Assuming that

the value of y for different gases is a continuous function of the molecular weight, its values in helium and argon will be respectively $12p$ and $27p$.

Hence the potential fall necessary to impart the ionising energy to the colliding ion in the two gases will be

$$V_h = XA_1 = \frac{X}{12p} \log. \frac{12p}{\alpha}, \quad V_a = \frac{X}{27p} \log. \frac{27p}{\alpha}.$$

Using the values of $\frac{X}{p}, \frac{\alpha}{p}$ corresponding to the point of contact of the tangent from the origin to the $\left(\frac{X}{p}, \frac{\alpha}{p}\right)$ curve (since for this point the ratio $\frac{X}{p}$ to $\frac{\alpha}{p}$ is as small as possible), this gives for the required potential falls the values

$$V_h = 6.25 \text{ volts, and } V_a = 12.4 \text{ volts.}$$

The corresponding potential for air is 5 volts.

The gases under consideration are thus somewhat more difficult to ionise by the collision of the negative ion than air.

* * * * * * * * * * *

The work described in the preceding paper was performed at the Cavendish Laboratory, Cambridge, and the writer desires to thank Professor Thomson for suggesting the problem and for his interest in its progress.

NOTE.

Since the above work was done and before the results were completed, a paper on the same subject was published by Messrs. Gill and Pidduck,[1] working under Professor Townsend. These experimenters used precisely the same apparatus and method as were used in Townsend's previous experiments.

In comparing their results with those of the present paper it will be seen that:—

(1) The values of $\frac{\alpha}{p}$ and $\frac{\beta}{p}$ for argon are quite similar, the latter being slightly higher in these experiments.

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[1] Gill and Pidduck, Phil. Mag., VI, 16, 280.

(2) The values of $\frac{\alpha}{p}$ for helium were slightly greater and of $\frac{\beta}{p}$ considerably greater than in their experiments. This is probably due to the fact that the helium used by Gill and Pidduck was slightly impure. Some values which they give for $\frac{\alpha}{p}$ for helium which had been repurified agree more closely with those of this paper, and, although they did not obtain a series of values for $\frac{\beta}{p}$ for the pure gas, they state that their experiments indicate that a slight amount of impurity has a very great effect in decreasing the value of $\frac{\beta}{p}$. In the present experiments the gas was very carefully purified, so that the results quoted are characteristic of pure helium.